♦ APPENDIX C. AN EXAMPLE OF ADAPTIVE MANAGEMENT USING CONCEPTUAL MODELS: CHINOOK SALMON AND DEER CREEK

OVERVIEW

This appendix provides an example of how Ecosystem Restoration Program (ERP) actions should be formulated and selected. The example given is for spring- and fall-run chinook salmon in the Deer Creek ecosystem (Figure C-1). Chinook salmon are a useful focus for this example because they are a valuable fish species, are sensitive to environmental conditions throughout the system, and integrate across the entire landscape of the Bay-Delta system. Spring-run salmon are of particular interest because their populations are a tiny fraction of their historical numbers and they have been proposed for listing as a threatened species. Fall-run chinook also have been proposed for listing, but their overall abundance is much higher than that of spring-run. The Deer Creek ecosystem is of interest because it is a relatively undisturbed stream, one of the last drainages in the Bay-Delta system to support spring-run chinook salmon, and because several specific restoration measures have been proposed for Deer Creek in recent years. In this appendix, we show how simple conceptual models can be used to evaluate various possibilities for rehabilitating salmon populations and habitat and how these might fit into the larger context of spring-run chinook life history and factors limiting its population.

BACKGROUND

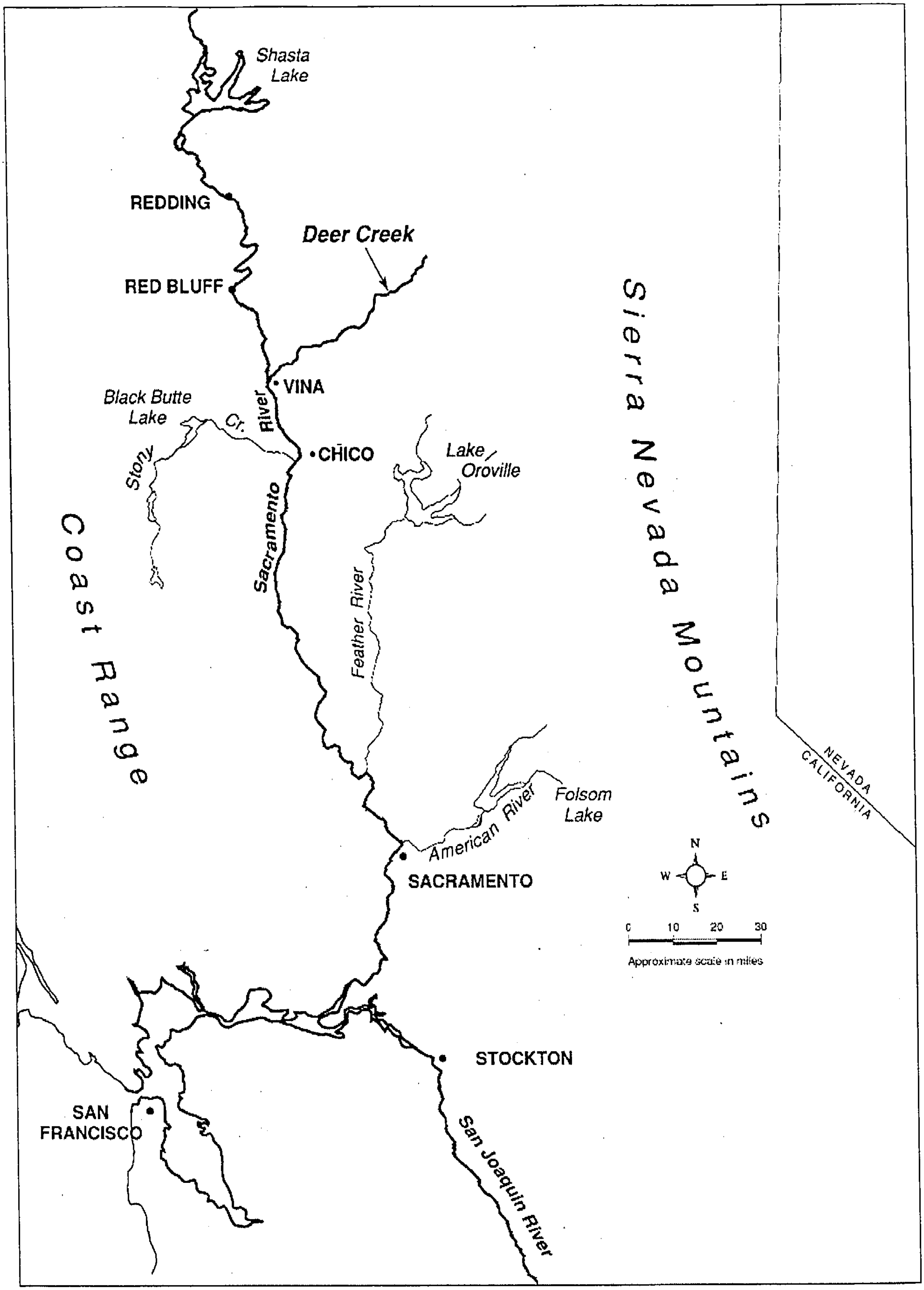
SPECIES-BASED VS. ECOSYSTEM-BASED RESTORATION

This example also illustrates the different assumptions underlying species-based and ecosystem-based restoration. Species-based restoration attempts to identify and remove limiting factors and bottlenecks to production. It requires specific knowledge about the species' life history and ecology that may be difficult to obtain and provides little progress toward ancillary objectives. On the other hand, it is easier to understand and justify and can capitalize on specific opportunities (e.g., harvest limits). Species-based approaches may be especially important for fishes such as chinook salmon that move between major ecosystems because removing limiting factors in one area may be offset by increased mortality in another area. Finally, state and federal endangered species legislation is essentially species based, although efforts are growing to apply them using ecosystem-based approaches.

Ecosystem-based restoration uses knowledge of the ecological context in which individual species thrive and attempts to restore that ecological context (structure and function) under the assumption that a species' well-being will emerge from a well-functioning ecosystem. It requires less knowledge about the species but incorporates the often-untested assumption that restoring the ecosystem will benefit the species. It can be used to achieve multiple objectives but also can be difficult to justify as a method for restoring individual species. As illustrated in this appendix, a comprehensive approach to ecosystem restoration, emphasizing an understanding and then restoration of physical and ecological processes affecting habitat, is likely to be more sustainable in the long term than attempts to create habitat features.

DEER CREEK CHINOOK SALMON LIFE HISTORIES

The life histories of spring- and fall-run chinook salmon are the same except for the seasonal timing of migration and spawning, the typical locations with the river system, and the length of time spent rearing in fresh water.


Shasta Lake
REDDING
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Black Butte Lake
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CHICO
Lake Oroville
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Coast Range
Sacramento
Feather River
NEVADA
CALIFORNIA
Folsom Lake
American River
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10
20
30
Approximate scale in miles
STOCKTON
SAN FRANCISCO
San Joaquin River

Spring-run chinook enter the rivers from the ocean from March through May. While migrating and holding in the river, spring-run chinook do not feed, relying instead on stored body fat reserves. They are fairly faithful to the home streams in which they were spawned, using chemical cues to locate these streams; however, some ascend other streams, especially during high-water years; in dry years, they may be blocked from their streams and forced to remain in main rivers.

Adult spring-run chinook migrate up Deer Creek from April through June (Vogel 1987a, 1987b), aggregate in the middle reaches (Airola and Marcotte 1985), and spawn from late August to mid-October. In Deer Creek, most hold and spawn between the Ponderosa Way bridge and upper Deer Creek falls, which is a natural barrier to migrating fish (Marcotte 1984). When they enter fresh water, spring-run chinook are immature; their gonads mature during the summer holding period (Marcotte 1984). Eggs are laid in large depressions (redds) hollowed out in gravel beds. The embryos hatch following a 5- to 6-month incubation period and the alevins (yolk-sac fry) remain in the gravel for another 2-3 weeks. After their yolk sac is absorbed, the juveniles emerge and begin feeding.

Historically, spring-run adults were a mixture of age classes ranging from 2 to 5 years old. Possibly because of fishing in the ocean, most of the fish now are probably 3 years old. During the summer holding period in freshwater pools, many large adult salmon may be caught by anglers (who snag them accidentally with spinning lures), and some by poachers. The importance of this source of mortality is indicated by the distribution of the fish; they are most abundant in the more remote canyon areas and scarce in pools close to roads.

Fall-run chinook salmon ascend Deer Creek from October through November (when they are sexually mature) and spawn immediately (October to early December), using gravels in lower elevation reaches, primarily in lower Deer Creek. Fall-run chinook spend less time in fresh water as adults and as juveniles, leaving their natal stream soon after emergence.

During most years, juvenile spring-run salmon in Deer Creek spend 9-10 months in the streams, where they feed on drift insects. The timing of emigration from Deer Creek has not yet been clearly determined, but it seems to be much more variable than for fall-run chinook. Some juveniles may move downstream soon after hatching in March and April, others may hold in the streams until fall, and still others may wait for more than a year and move downstream the following fall as yearlings (Harvey pers. comm.). The outmigrants may spend time in the Sacramento River or estuary to gain additional size before going out to sea, but most have presumably left the system by mid-May. Once in the ocean, salmon are largely piscivorous and grow rapidly. During downstream migrations in the Sacramento River and Delta, the smolts presumably stay close to the banks during the day (near cover) and then move out into open water at night, to migrate. Historically, they may have moved into flooded marshy areas in the Delta to feed, but there is little evidence of such activity today.

STATUS OF CHINOOK SALMON POPULATIONS

Spring-run chinook salmon are in a state of decline and are listed by the State as threatened species and are federally proposed for listing as endangered (see ERPP Volume I, Species and Species Groups Visions); therefore, actions likely to protect and enhance this stock should receive high priority. At the same time, actions to protect and improve habitat should help not only spring-run chinook, but also other fish, such as fall-run chinook, steelhead, Pacific lamprey eel, and a complete assemblage of native foothill fishes and native amphibians. Similarly, actions to benefit spring-run chinook habitat probably would achieve other objectives at the ecosystem level. The principal assumption is that restoration of habitat will be effective in improving conditions for this stock.

Spring-run chinook salmon of the Sacramento-San Joaquin River system historically comprised one of the largest set of runs on the Pacific coast. Campbell and Moyle (1991) reported that more than 20 "historically large populations" of spring-run chinook have been extirpated or reduced nearly to zero since 1940. The three largest remaining runs (Butte, Deer, and Mill Creeks) have exhibited statistically significant declines during the same period. The only substantial, essentially wild populations of spring-run chinook remaining in California are in Deer and Butte Creeks in the Sacramento River drainage and in the Salmon River in the Klamath-Trinity River drainage (Campbell and Moyle 1991).

In Deer Creek, spring-run chinook abundance has been low since the early 1980s (Figure C-2). The Mill and Big Chico Creek populations have suffered similar declines, but the Butte Creek population has not, for reasons that are uncertain.

Fall-run chinook populations have also declined, but not so precipitously. In large part, this decline has been less severe because, unlike for the spring-run chinook, access to the fall-run chinook's (lower elevation) spawning grounds has not been cut off.

HABITAT RESTORATION PROPOSED FOR DEER CREEK

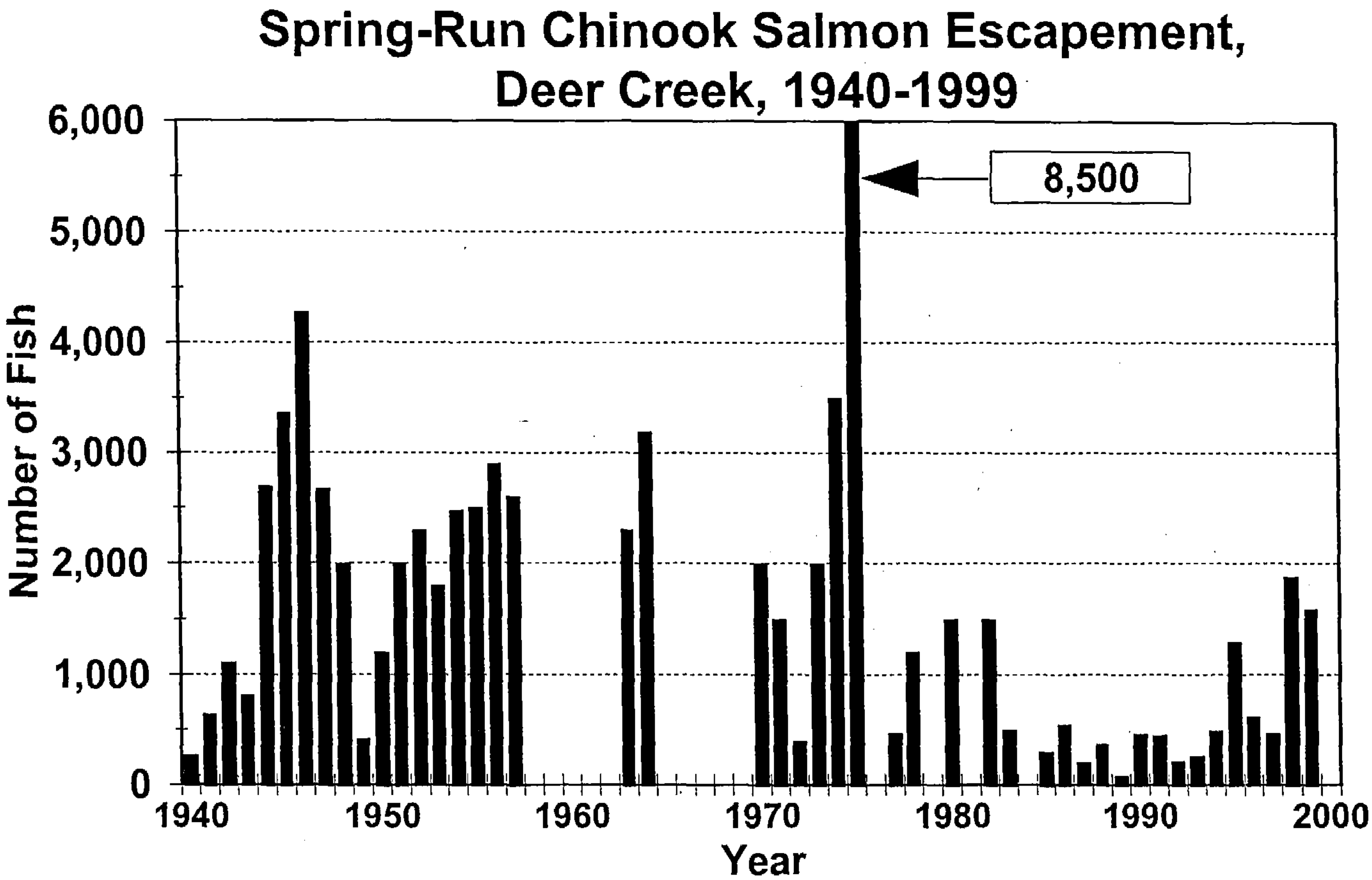
With declining salmon returns throughout the Bay-Delta system and the extinction of spring-run chinook in most of the rivers they formerly inhabited, Deer Creek and the other remaining spring-run chinook streams have attracted attention, and various proposals have been put forth to enhance salmon habitat and passage. These proposals have included measures such as minimum flow requirements in reaches formerly de-watered below irrigation diversions. Although there may be argument about the amounts of water needed, minimum flows in the reach are clearly required.

Other proposed measures have addressed the apparent armoring of the bed of Deer Creek, through mechanical ripping of the gravelbed, artificial addition of smaller gravel, and installation of log structures to hold the imported gravel in place (California Department of Fish and Game 1993, U.S. Fish and Wildlife Service 1995, CALFED Bay-Delta Program 1997). The relative lack of riparian vegetation on the banks along most of lower Deer Creek was addressed by the proposed planting of riparian trees. Although measures such as adding smaller gravel to the channel may provide short-term benefit, the shear stresses in the channel are so high that the gravels would be likely to wash downstream during the next flood. Similarly, in-channel structures and even riparian bank plantings may be washed out during high flows under present channel conditions.

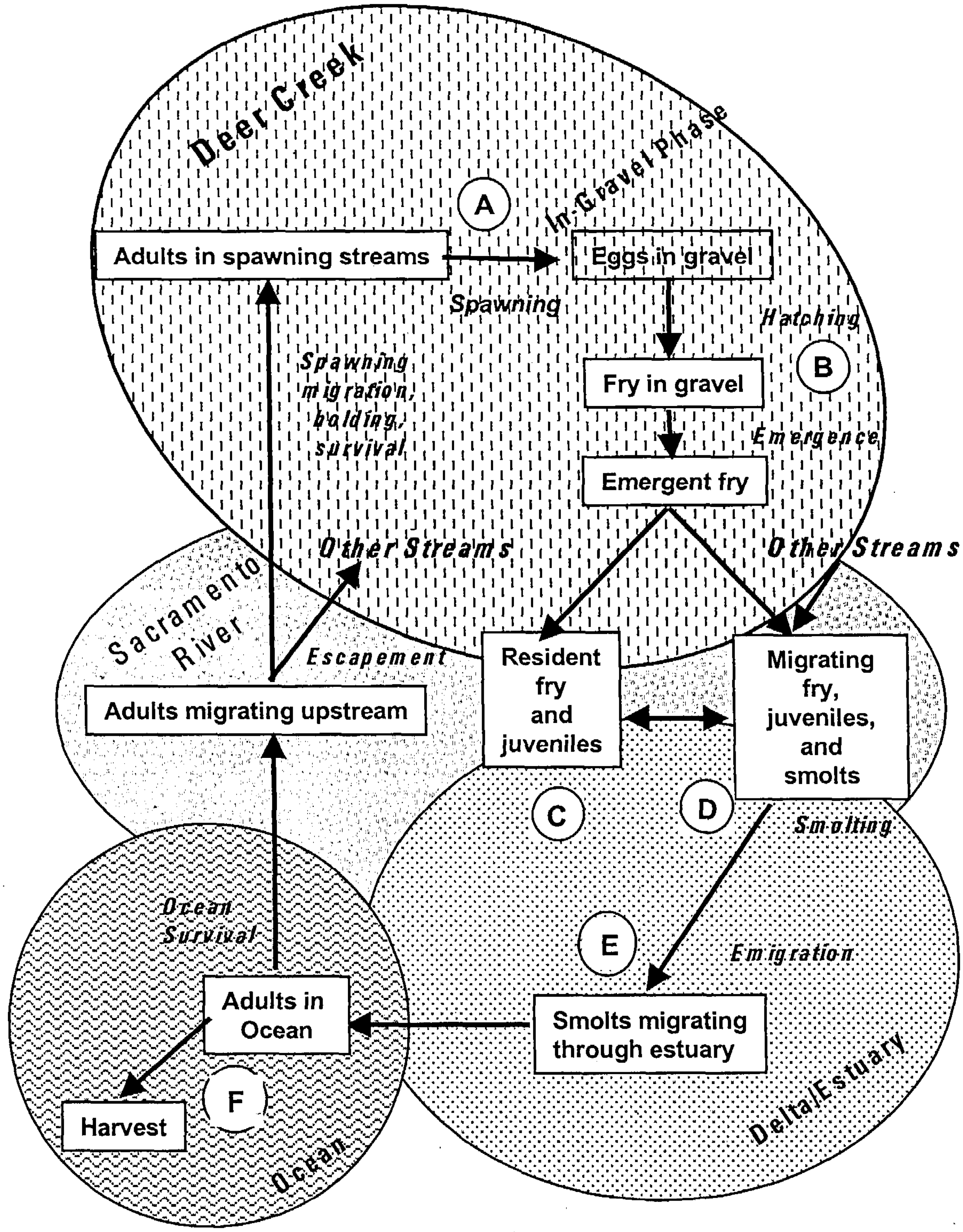
OVERALL CONCEPTUAL MODEL FOR SPRING-RUN CHINOOK SALMON

Figure C-3 shows a schematic diagram of the life cycle of spring-run chinook salmon in Deer Creek. Beginning with the ocean phase, surviving adults migrate upstream to hold through the summer and then spawn. Spawning, hatching, and initial rearing take place within Deer Creek. Rearing juveniles may remain in Deer Creek or begin moving downstream, some moving as far as the Delta. The distribution of spring-run juveniles that survive is not known. Spring-run salmon may smolt and migrate to sea in their first winter-spring, or the following winter as yearlings.

Efforts to restore habitat for spring-run chinook salmon within Deer Creek must be considered in the context of the species' life cycle. Restoration of habitat for one life stage may have little effect if other life stages are limiting. Furthermore, different stages in the life cycle could be limiting at different times, and releasing a limit at one part of the life cycle could result in another part of the life cycle becoming the limiting point. Circled letters on Figure C-3 show points in the life cycle at which interventions might be possible to restore habitat and conditions: (A) survival during migration to and holding near spawning areas, which may be affected by flow conditions or mortality including fishing; (B) spawning habitat, which may be affected by area of gravel of suitable quality in suitable hydraulic conditions, flow and variability in flow, and temperature; (C) rearing habitat including Deer Creek, the Sacramento River, and the Delta, which may be affected by flow, connection to floodplains, riparian vegetation, diversions, and temperature; (D) survival during migration down the river, which may be affected by flow, temperature, hatchery releases, predators, and diversions; (E) passage through the Delta, which may be affected by flow in the river, net flow across the Delta, temperature, contaminants, agricultural diversions, and possibly export flow; and (F) ocean survival, which is affected by ocean conditions and the percentage of salmon harvested.



Note: Data from Candidate Species Status Report 98-01 to the Fish and Game Commission.



Note: The four oval areas represent the four major geographic regions. Arrows indicate a change of state of surviving salmon, with only ocean harvest mortality displayed explicitly. Terms in italics indicate the major transformations occurring in each phase.

Density-dependent and density-independent factors affect salmon populations differently. Of the factors limiting the abundance of salmon, saturation of spawning habitat by high densities of redds, or possibly saturation of favorable rearing habitat by large numbers of juveniles, may result in density-dependent effects. In the case of spawners, this happens because females spawn in fairly restricted areas of high-quality habitat, and the resulting crowding, which can occur even at fairly low numbers of spawners, results in lower survival of the early-spawned eggs (superimposition). If this happens, providing more habitat or improving habitat quality should increase population size by increasing carrying capacity, thereby lifting the limit; however, if the population is too low for significant density-dependent mortality to occur, density-independent factors, mainly downstream, will predominate. In that case, habitat restoration upstream will have little if any effect on population size.

The current low abundance of spring-run salmon suggests that the population may not be greatly influenced by density-dependent effects, but until specific studies are made of this issue it cannot be resolved. In the meantime, ecosystem restoration can also be justified, along with actions designed to reduce density-independent mortality in other parts of the life cycle, because of other objectives (e.g., goal 2, ecological process objectives for high flows and floodplain inundation; goal 4, habitat objectives for tidal marsh and riparian wetlands).

A conceptual model of fall-run chinook salmon would be similar to that of spring-run except that the length of residence of juveniles and adults in the stream and use of the Delta for rearing by juveniles would be much less and the seasonal timing of migration would differ.

GEOMORPHIC AND HYDROLOGIC SETTING

Deer Creek drains 208 square miles of volcanic rocks on the west slope of Mount Lassen. It flows through canyons cut into volcanic strata before debouching onto the Sacramento Valley floor, flowing across its alluvial fan, and joining the Sacramento River near Vina (Figure C-1). For its first 2 miles, lower Deer Creek (the alluvial reach on the Sacramento Valley floor) migrates across an active channel 1,000-2,000 feet wide, bounded by bluffs (typically 5 meters [m] high) of older, cemented river gravels (Helley and Harwood 1985). Downstream of the bluffs, the multiple channels characteristic of alluvial fans can be clearly seen in the contour lines (Figure C-4). These contour lines reflect the process by which alluvial fans build up: A channel (or more than one channel) is active at a given time, carrying sediment from the watershed, and (because of the flattening of the gradient on the valley floor) aggrades (builds up with sediment) until the creek abandons that channel in favor of another channel, which now offers a higher gradient, until it too aggrades and the channel shifts again. Thus, over centuries or millennia, the locus of deposition shifts around the entire alluvial fan such that a low-gradient cone of sediment is created.

Strong, cold base flows are maintained in Deer Creek by springs in the volcanic rocks. The average flow at the U.S. Geological Survey gauge (located at the transition from the bedrock canyon to the valley floor) is 317 cfs (Mullen et al. 1991). Despite the base flows from the watershed, parts of Lower Deer Creek have been dry during the summer and fall of many years because of irrigation diversions. Dewatering of the stream no longer occurs thanks to voluntary releases by the irrigation districts, but the dewatered reach has been a barrier to migration until recently, and adequate flow to maintain cool temperatures remains an issue.

There is a high snowmelt flow virtually every year (forty percent of the Deer Creek watershed lies above 4,000 feet), but most big floods result from warm winter rains, and the biggest floods derive from warm rain on snow events. Deer Creek experienced such a rain-on-snow flood of 20,800 cfs in January 1997, which damaged farmland, and nearly washed out the under-sized Leininger Road bridge. The 1997 flood was only the third largest flood in the period of continuous record for the stream gauge, 1921-present, and is thus considered a 25-year flood (following standard formulae for flood frequency analysis) (Dunne and Leopold 1978). Other important floods occurred in December 1937 (23,800 cfs), 1940 (21,600 cfs), December 1964 (20,100 cfs), and 1970 (18,800 cfs) (published records and preliminary estimates of the U.S. Geological Survey). It is during such large floods that Deer Creek would historically shift

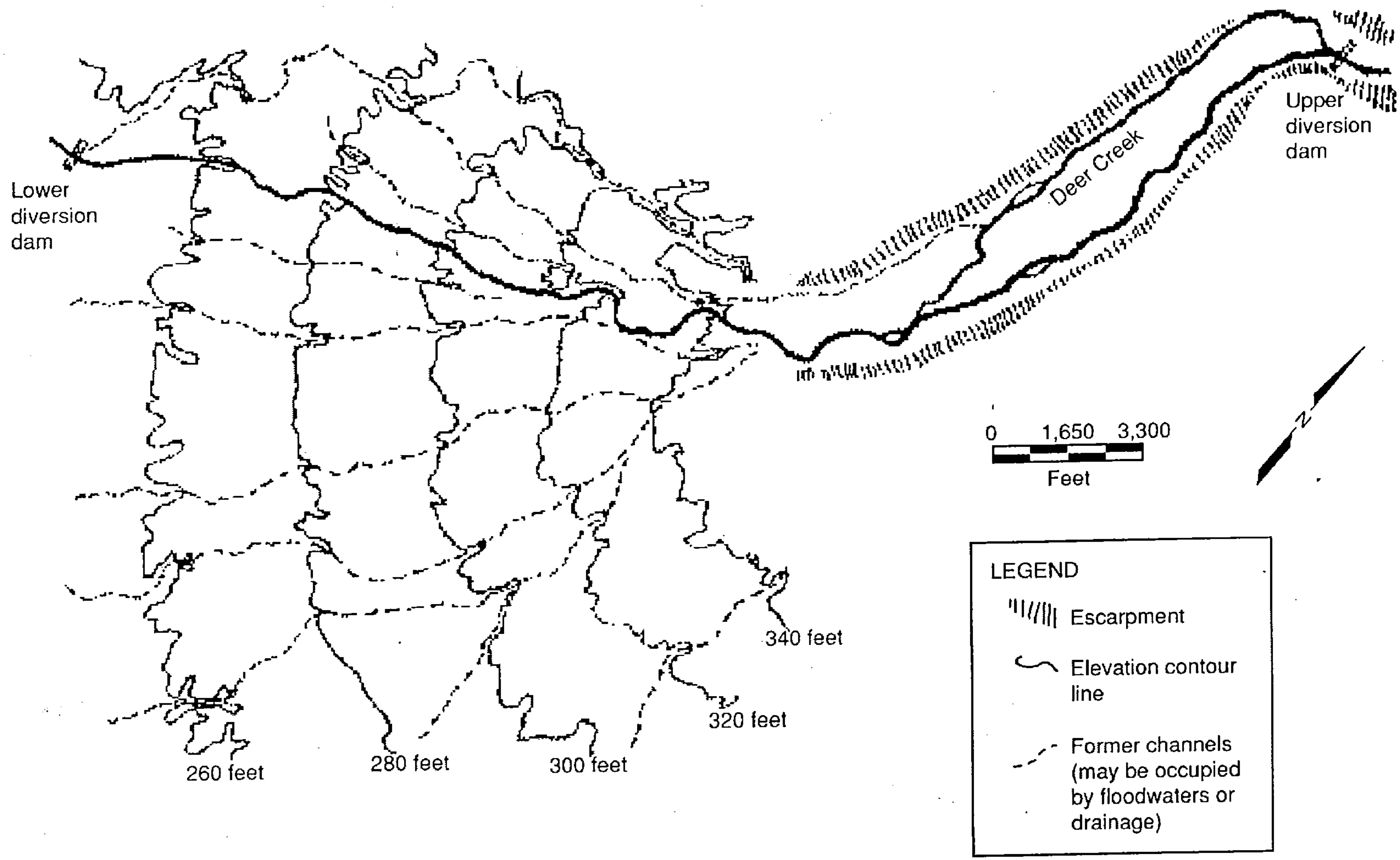


Figure C-4: Characteristic Multiple Channels Radiating from the Apex of the Alluvial Fan on Deer Creek channels. About ten miles of levees were built by the U.S. Army Corps of Engineers along Lower Deer Creek in 1949 to control flooding. During the 1997 flood and others, Deer Creek overflowed its banks, washing out levees on the south bank, and flowed across the floodplain for about 2 miles down to U.S. Highway 99, following another of the many distributary channels of the alluvial fan.

Habitat Change from Historical Geomorphic Analysis

Historical aerial photographs taken in 1939 clearly show Lower Deer Creek was highly sinuous, with small-scale bends, point bars, and alternating pools and riffles. For much of its course, the low-flow channel was against cut banks with overhanging trees, which provided the channel with habitat under cut banks and roots, shading of the stream, input of nutrients and carbon, and large woody debris. The bends in the channel created secondary circulations and complex flow patterns, which produced zones of higher and lower shear stress distributed through the channel, which in turn led to deposition of gravels and other sediments (Deer Creek Watershed Conservancy 1998). The complexity of channel form resulted in a diversity of microhabitats for invertebrates and fish. During floods, Deer Creek would regularly overflow its banks and inundate adjacent floodplains, a process which prevented continued build-up of water depth in the channel and thus limited the increase in shear stress on the channel bed. Inundation of the floodplain had numerous other ecological benefits, such as providing fish with refuge from high velocities and abundant food sources on the floodplain, and watering the floodplain to maintain vegetation and floodplain water bodies (Stanford and Ward 1993, Sparks 1995).

Habitat conditions in Deer Creek were profoundly changed in 1949 by a U.S. Army Corps of Engineers flood control project, which built over 10 miles of levees along Deer Creek and straightened and cleared the low-flow channel. In effect, the flood control project sought to confine flood flows to the main channel, which required levees to prevent overflow, and increasing the capacity of the main channel by reducing its hydraulic roughness through straightening and clearing vegetation and large woody debris. Since 1949 there have been repeated efforts to maintain the flood control channel and levees by the U.S. Army Corps of Engineers, the California Department of Water Resources, and Tehama County Flood Control. After each major flood, heavy equipment was usually used to repair levees and clear the channel of gravel bars and large woody debris, with a particularly large gravel removal project after the 1983 flood by the Department of Water Resources (Deer Creek Watershed Conservancy 1998). Gravel removal and levee repair in the early 1980s cost about $1 million, and similar work in 1997 cost about half that amount.

Beginning with the aerial photographs of 1951 (the first available after the flood control project) and continuing to the present, the low-flow channel of Deer Creek is visibly less sinuous and less vegetated than it was in 1939. The alternating pool-riffle sequences visible on the 1939 aerial photographs have been largely replaced with long riffles and runs. There is less riparian vegetation bordering the low-flow channel, partly because there is less riparian vegetation on the banks and partly because there are fewer points where the (now straightened) low-flow channel is undercut at the base of a wooded bank.

Although there are no data on the bed material sizes before 1949, a number of reports have speculated that the gravels of Deer Creek are "armored" (California Department of Fish and Game 1993, U.S. Fish and Wildlife Service 1995, CALFED 1997). While Deer Creek probably does not fit the geomorphic definition of 'armored' (Dietrich et al. 1989), it is very likely true that the bed material is substantially coarser now than before 1949. The reason is that smaller gravels (which would be preferred by most spawning salmon) are now transported out of Deer Creek to the Sacramento River due to the increased shear stresses in the straightened and leveed channel.

The 1949 flood control project and subsequent maintenance efforts were undertaken with good intentions and reflected the best thinking at the time, but there is increasing recognition worldwide that channelization and other river control efforts are frequently detrimental to aquatic and riparian habitat, and often expensive to maintain because they are, in effect, "fighting" river processes. The literature is replete with evidence that natural, complex channels (i.e., channels with irregular